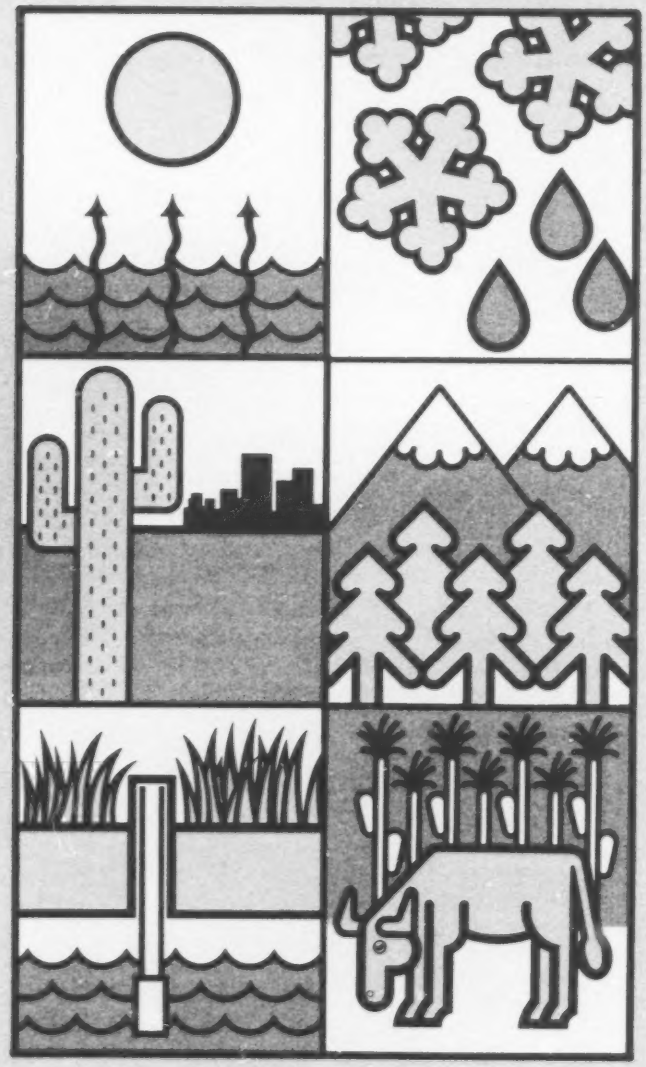
Water-Related Technologies

for Sustainable Agriculture in U.S. Arid/Semiarid Lands



Summary

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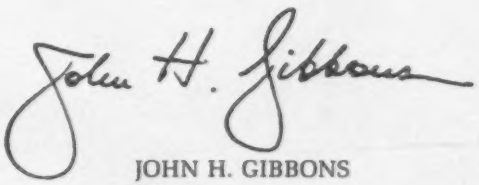
Foreword

Water is a major limiting factor in most areas where Western arid and semiarid agriculture is currently practiced. Increasing water demands from nonagricultural users plus growing problems of ground water depletion, salt buildup in agricultural soils, and water-quality deterioration are causing heightened concern about the sustainability of Western agriculture. A major part of this concern is focused on whether the Federal agricultural system is prepared to meet the changing needs of Western agriculture and whether technology can assist in providing the Nation with Western agricultural production that is sustainable and profitable over the long term.

This summary presents the major findings of an assessment of existing and emerging water-related technologies for their ability to support long-term productivity of arid/semiarid agricultural plants and animals in the context of institutional factors, water supply/use relationships, and the characteristics of the renewable natural resource base on which agriculture depends. The study, which focuses on the 17 Western States, was requested by the House Committee on Agriculture and endorsed by the Senate Committee on Environment and Public Works, Subcommittee on Water Resources. The technologies examined by the study are generally directed toward: 1) improving efficiency of water use, whether for rain-fed (dryland and rangeland) systems or irrigation; 2) improving water management, storage, and distribution for agriculture; and 3) augmenting existing supplies with additional water not previously available for agriculture.

The Office of Technology Assessment (OTA) greatly appreciates the contributions of the advisory panel, working groups and workshop participants assembled for this study, the authors of the technical papers, and the many other advisors and reviewers who assisted us, including farmers, ranchers, agricultural scientists in government and universities, and experts in the private sector. Their guidance and comments helped develop a comprehensive report. As with all OTA studies, however, the content of the report is the sole responsibility of OTA.



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Water-Related Technologies for Sustainable Agriculture in U.S Arid and Semiarid Lands

INTRODUCTION

Agriculture as it is known today in the arid/semiarid United States is being increasingly threatened by water-related problems. Some Western States are experiencing resource limitations related to water use and distribution that challenge the full capacity of existing social and technical institutions. The water problems to face this region and, therefore, the Nation in the 1980's and 1990's are likely to expand and intensify for agriculture. Federal agricultural and water-related institutions are poorly prepared for the long-term needs brought about by these problems. Change in patterns and manner of water use in some areas is likely to have severe effects for agriculture. Whether change ultimately produces a sustainable Western agriculture that strengthens the agricultural producer, the region, and the Nation depends in part on the role the Federal Government chooses or declines to play in the coming few years.

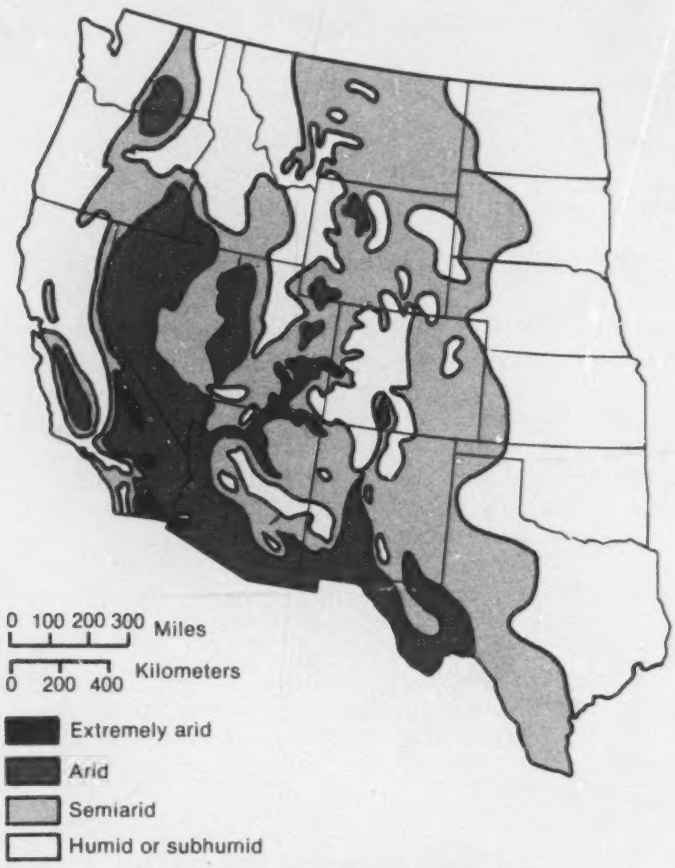
This study assesses the role of present and emerging water-use technologies for sustaining the long-term agricultural productivity of arid/semiarid agricultural plants and animals and the renewable natural resource base on which agriculture depends. The study considers increased demands on the resource, concerns about water quality, and the capacity of existing institutions to respond effectively and equitably to growing demands. Congressional interest in this topic is important because the arid/semiarid West (fig. 1) makes significant contributions to this country's agricultural production, providing unique benefits not easily replaced by the other regions of the United States. Its large expanses of land nurture cereal grains and livestock. Its dry and disease-free environment is especially suited to seed production and certain kinds of agricultural research. When irrigated, its soil, aided by low humidity and many cloud-free days, produces high-value specialty crops such as fruits, nuts, and table vegetables. Much of the research and development (R&D) of agricultural technology that now benefits the entire United States originated in the West, where water application could be carefully controlled.

MAJOR FINDINGS

The following three major findings of this assessment are the synthesis of individual chapter findings which are discussed in more detail below:

- If agriculture in the Western United States is to be conducted in a sustainable fashion, a systems approach to decisionmaking regarding policies, plans, and programs affecting the agricultural resource base and water-related technologies is a fundamental need, one that generally is lacking throughout government.

Figure 1.—Arid and Semiarid Regions of the United States



SOURCE: Carle Hodge (ed.), *Aridity and Man* (Washington, D.C.: American Association for the Advancement of Science, publication No. 74, 1963).

- A committed Federal role is fundamental for helping to sustain long-term productivity of the agricultural resource base in the Western States, but currently this goal is not being advanced effectively by some existing Federal activities.
- To ensure sustainable Western agriculture, users must be involved in and must perceive equity and fairness in decisionmaking about water-related technologies and resolution of conflicts over water use. Improved mechanisms are needed to expand this involvement.

Western Agricultural Production

Products of Western agriculture constitute a large share of the total income derived from farming and ranching in the United States. In 1980, cash receipts from marketing crops and livestock and their products in the Western States accounted for approximately $59.3 billion, or about 43 percent of the income derived from farming in the United States. Some 30 percent of this sum came from export markets.

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Unlike the Eastern United States, much of the land in the West is federally owned:

	Federal	Non-Federal	Percent Federal
	(in millions of acres)		
17 Western States	368	790	32
31 Eastern States	34	705	5

The amount of public land varies from State to State, from some 85 percent of Nevada to about 1 percent of Kansas and Nebraska. These public lands are used largely for livestock grazing and include major water-producing areas. The Federal ownership of these lands has generated Federal policies on use and management, policies that can substantially affect the sustainability of Western agriculture.

Of the three types of agricultural production (see box A) used in arid/semiarid regions, rangeland and dryland agriculture are the most extensive in area and rely on precipitation for water supplies. **Rain-fed agriculture makes important contributions to the economy and lifestyle of the West and is likely to increase in importance.** Present-day irrigation agriculture is especially significant because of the large amounts of energy and supplemental water involved. It allows crop production in areas where it might otherwise be impossible, and farmers who irrigate generally have higher and more stable yields and can risk growing crops of higher value. However, irrigation agriculture is the subject of particular controversy and concern at present. Some crops that are irrigated are surplus. Moreover, competition for these water resources is increasing from industries and municipal users who can afford to pay more for their water. Finally, depletion of ground water resources threatens agricultural producers and rural communities and diminishes the possibility of using this resource in the future. These factors lead many analysts to believe that **in the future Western irrigation agriculture as practiced today will diminish in productivity and profitability in some areas.**

Water Supply and Use

Available estimates of water supply and use indicate that **almost half of the Western United States is experiencing water-supply problems in relation to demand.** Surface water shortages exist annually or seasonally in at least some portion of each of the major water resources regions of the Western States.

Box A

Three broad types of agricultural production are common in arid/semiarid regions:

- Rangeland agriculture—usually involves grazing domestic livestock on grasses, grasslike plants, forbs, and shrubs on lands traditionally considered unsuitable for cultivation.
- Dryland farming—involves crop production through cultivation of the land and relies on precipitation to supply plant-water needs.
- Irrigation agriculture—involves crop production through land cultivation and uses additional water to supplement normal precipitation.

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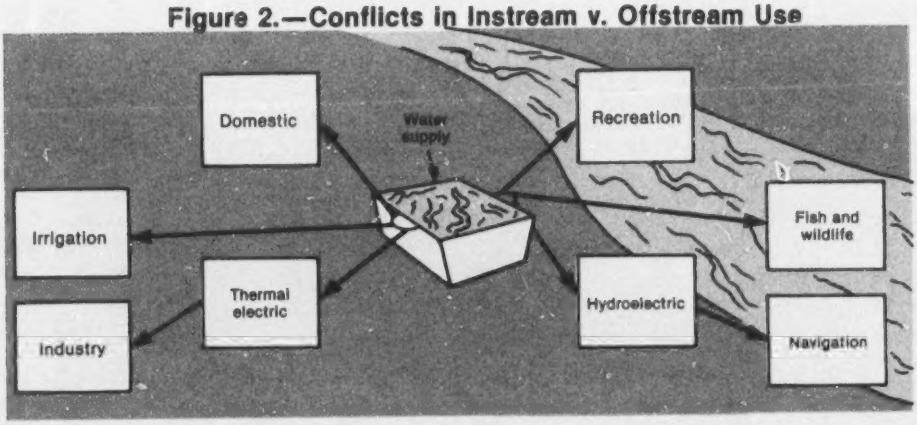
In almost all cases, these shortages are offset by water reuse and ground water pumping. In much of the Southwest and southern High Plains, ground water is being withdrawn faster than it is replaced (often called ground water "mining") in order to sustain developed levels of use. Where water supply is not being consumed, competing nonconsumptive uses, such as instream flow requirements for hydroelectric generation, waste assimilation, recreation, and habitat maintenance, increasingly create scheduling conflicts for offstream uses (fig. 2). **Present trends and experience indicate that every additional drop of Western water conserved, and thus available, enables more growth and development, raising demand levels further.**

The availability of water for agricultural use varies by location and over time. The potential for a given technology to produce additional water or to conserve existing supplies is difficult to evaluate and will remain so unless the quantities of water involved in the hydrologic cycle can be defined more accurately. Various responsibilities for the collection, synthesis, and dissemination of hydrologic information are delegated among a number of Federal and State agencies (table 1), resulting in a variety of data bases and data interpretations that are often not compatible. **Important gaps in data exist, and few regional syntheses of data have been made.** Short-term climatic fluctuations affecting water supply can be accommodated in management and planning processes through statistical analysis of past trends; there is no reliable method for predicting long-term fluctuations.

The most important source of renewable surface water supplies in the Western United States is the mountain snowpack. When the snowpack melts in the spring and summer, it supplies an estimated 70 to nearly 100 percent (depending on location) of the total annual surface runoff for much of the Western United States. Relatively little research attention has been given to the snowpack. Technologies such as weather modification and the forecasting of streamflow to improve reservoir management would benefit considerably from increased understanding of the snowpack's dominant role in renewing surface water supplies.

Figure 2.—Conflicts in Instream v. Offstream Use



SOURCE: U.S. Water Resources Council, *The Nation's Water Resources 1975-2000*, vol. 2, part III (Washington, D.C.: U.S. Government Printing Office, 1978), p. 129.

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Table 1.—Federal Water-Data Collection Agencies[a]

	Government agencies						Independent agencies			
In-house data programs	USDA	DOC	DOD	DOE	DOI	DOT	EPA	IBWC	NRC	TVA
Surface water	X	X	X	X	X	X	X	X	—	X
Ground water	X	—	X	X	X	X	X	X	—	X
Water quality	X	X	X	X	X	X	X	X	—	X
Water use	X	X	X	X	X	—	—	—	—	—
Environmental impact	X	—	X	X	X	X	X	—	—	X
Ecology	X	—	X	X	X	X	X	—	—	X
Management effects	X	—	X	X	X	X	X	—	—	X
Basin studies	X	—	—	—	X	X	X	—	—	X
Real-time sensing	X	X	X	—	—	X	X	—	—	X
Remote sensing	X	X	X	—	—	X	X	—	—	X
Data sensing	X	—	X	X	X	—	X	—	—	X
Instream use	X	—	—	—	X	—	—	—	—	—
Water rights	X	—	—	—	X	—	—	—	—	—
Floods	—	X	—	—	X	X	—	—	—	X
Energy	—	—	—	X	X	—	X	—	X	—
Nuclear	—	—	—	X	X	—	X	—	X	—
Precipitation quality	—	—	—	—	X	—	X	—	—	X

KEY: USDA—U.S. Department of Agriculture; DOC—Department of Commerce; DOD—Department of Defense; DOE—Department of Energy; DOI—Department of the Interior; DOT—Department of Transportation; Independent agencies: EPA—Environmental Protection Agency; IBWC—International Boundary & Water Commission; NRC—Nuclear Regulatory Commission; TVA—Tennessee Valley Authority.

[a]For the 1981-82 fiscal year, 26 Federal agencies, representing six departments and four independent agencies, collected water resource data.

SOURCE: U.S. Department of the Interior, Geological Survey, Office of Water Data Collection, *Plans for Water Data Acquisition by Federal Agencies Through Fiscal Year 1983* (Reston, Va.: 1982), p. 7.

Water Quality

Since the volume of water in the Western United States is lower than that in the more water-abundant Eastern part of the country, any given water use in the West has a greater potential for causing water-quality degradation. The limited supply of Western water requires that each unit of water be more fully used, resulting in patterns of reuse in which each unit of water is used consecutively as it moves downstream. Thus, water may be removed from a river and partially consumed for irrigation; the return flow may be stored in a reservoir and subsequently reused to generate hydroelectric energy; and the remainder may be withdrawn by a municipality for human consumption. The return flows from each of these uses often have increasing levels of pollution that, left untreated, can threaten downstream uses including agricultural uses.

Most water-quality problems appear to be site-specific. The data base describing the quality of water in the Western United States is incomplete, however, and few integrated analyses of water contamination as it affects water reuse, environmental characteristics, or public health have been performed.

The highest quality water required in agriculture is for domestic farm and ranch consumption. Much of the water used in this way is well water, which in many areas is not routinely monitored for quality nor subjected to any routine treatment prior to use. The quality of this water source is particularly suscep-

tible to degradation because of the many potential sources of contamination in the farm and ranch environments.

The quality of water used in irrigation is also very important. When water applied in irrigation is lost to evapotranspiration during plant growth, salts contained in that water are left behind in the soil. **Continued reuse of streamflows for irrigation without prior treatment has become a necessity in many of the water-short areas of the Western United States. This reuse can result in the gradual buildup of salts and agricultural chemicals in the soil and in water that is ultimately detrimental to long-term agricultural productivity.**

Institutions Affecting Western Agricultural Water Use

Distribution of water in the Western United States among uses and users responds to two major institutional forces—the legal system and the economic ("market") system. **The Western agricultural water user is, at best, moderately uncertain about future water use and the adoption of technology affecting water use because it is unclear how legal and economic institutions might change as demands for water increase.**

At the time Western law doctrines were developed, the level of definition given to water rights and duties was adequate to address early development needs. **As water-use demands increase and values change, more precise definition of such concepts of beneficial use will be required to allow the user greater assurance of return on investments in water "saved."**

Growing demands are creating conflicts among agricultural, energy, industrial, municipal, Federal reserved water-right holders, environmental, and other uses and values and suggest that water in the West will become more expensive. Until now, Federal sponsorship of many development activities provided water at well below its "cost" or "value" relative to much non-Federal water. This sponsorship has slowed the development of Western water markets and has shaped the character and patterns of agricultural water use in the Western United States. However, as demands for water for nearly all purposes increase and as the scarcity of water is recognized, pressures will mount to shift water to new uses and users. **Transferring substantial amounts of water to a new use will have a profound effect on the people and on the supporting resources that are left behind.**

In the past two decades, States have begun to take a more active role in resolving growing conflicts over water use. However, **direct Federal involvement to address Federal water issues, topics of broad geographical jurisdiction, international impacts, and equity concerns and to support and assist States' efforts will be necessary to ensure the sustainability of Western agriculture.**

Technologies: Making Optimal Use of the Hydrologic Cycle for Arid/Semiarid Agriculture

Evidence suggests that some existing and emerging technologies have potential for sustaining the long-term productivity of Western agriculture. Effective application requires an understanding of their interrelated impacts on the agricultural resource base. Technologies were assessed according to the principal components of the hydrologic cycle (fig. 3) the technologies are meant

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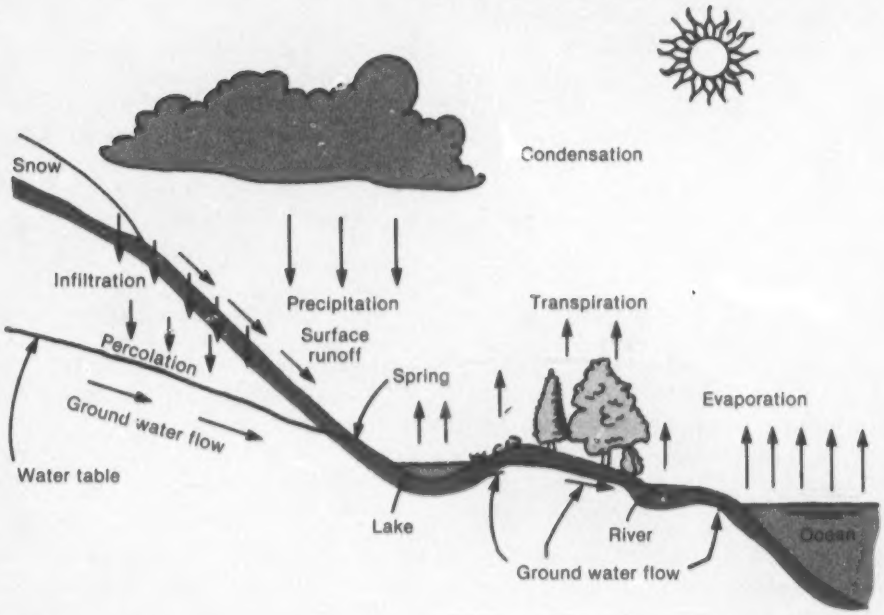
Figure 3.—The Hydrologic Cycle



Water passes continuously through this cycle from evaporation from the oceans into the atmosphere through precipitation onto the continents and eventual runoff into the oceans. Human use of water may modify this cycle at virtually every point.

SOURCE: H. Hengeveld and C. DeVocht, *Urban Ecology* 6(1-4):19, 1982.

to manipulate. Because water is a key factor dictating the types of agriculture that can be sustained in the water-short West, knowing the impacts of a particular water-related technology throughout the water system is critical. Benefits to one user upstream could mean losses to another user downstream in reduced flow, reduced quality, or altered timing of flow. Alterations in surface water at one site could affect ground water supplies at another hydrologically interconnected site.

Technologies Affecting Precipitation and Runoff

The renewable water resources of the West originate as precipitation from air masses moving across the region. Surface runoff represents that fraction of this precipitation not consumed by evapotranspiration or infiltrated into the soil and ground water. Three major classes of technology have evolved around modifying or anticipating the surface runoff fraction of the original precipitation: weather modification, watershed management, and water-supply forecasting. Each of these technologies has some potential on at least a local, site-specific basis. Evidence does not yet exist, however, to demonstrate that these are generally accepted operational technologies for sustainable agriculture.

Evaluation of any technology designed to modify or forecast precipitation and/or runoff from hydrologic environments in the region would benefit from a more integrated approach to the study of the hydrologic regimes of the Western United States than that which now exists. Moreover, hydrologic research activities and priorities should reflect the fact that most of the annual surface

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runoff and ground water recharge in the West comes from the mountain snowpack.

WEATHER MODIFICATION

Weather-modification ("cloud-seeding") technologies are designed to increase the amount of precipitation over that which occurs naturally. This is done by injecting artificial nucleating agents, such as silver iodide, into suitable air masses. **This technology has been developed within a solid scientific framework creating a body of knowledge that should facilitate future advances.**

WATERSHED MANAGEMENT

No proven technologies exist to increase water yield from the mountain alpine zone (zone above the timberline). This area may be the most efficient and productive source of water in the Western United States, and a passive, conservative management approach may be the most beneficial and effective management technology at present for downstream users.

In certain situations in the montane zone (the timbered zone) of mountain ranges, vegetation management through timber harvesting may produce local increases in water yield. It may be difficult, however, to detect increased yields at points downstream where arid/semiarid agriculture is practiced because such increases, when combined with the entire volume of watershed runoff may not be discernible using existing stream-gage technologies. Moreover, the ability to predict results on an unstudied watershed is difficult because of the range of hydrologic environments in the mountains of the West relative to that represented by existing experimental results. At some sites the effects of timber harvest on soil erosion, other components of the hydrologic cycle, or existing wilderness values may negate potential beneficial effects for downstream arid/semiarid agriculture.

In most cases in the lowland watersheds where the dominant vegetation consists of shrubs and grasses, management should emphasize forage production and erosion prevention rather than surface runoff production. Where surface runoff is collected and used for cultivated crops and animal watering (runoff agriculture), water-management practices can provide an important local water supply.

STREAMFLOW FORECASTING

Water-supply forecasting is one of the most important technologies related to precipitation and runoff in the Western United States for long-term sustainable agriculture. Improvements in the accuracy of these technologies will entail advances in understanding the impacts of weather modification and watershed management on the hydrologic environment. **Improved water-supply forecasting could provide the link between the resource and the water user or planner because it directly relates to the timing and volume of water available to downstream or lowland agriculture.** A wide range of forecast models exists, from very sophisticated computer simulation technology to simpler statistical correlation models. Research has indicated that no single forecast model may be sufficient for all the hydrometeorological environments in the West. Research also suggests that progress in accurately forecasting streamflow for certain regions in the Western United States would reap considerable economic benefits for agriculture.

Technologies Affecting Surface Water Storage and Delivery

Currently, opportunities to develop large sources of previously unavailable surface water or to augment existing supplies are feasible technologically but are limited by economic, environmental, legal, and social considerations. They are unlikely to add significant amounts of water to irrigation supplies in the future. Technologies that reduce water losses (i.e., conserve water) in storage and delivery systems can be applied relatively easily but tend to be expensive. In addition, their effects on the entire hydrologic cycle are often difficult to measure and their application, at times, can have unexpected, negative effects on riparian (areas of shrubs, trees, and grasses generally along streambanks) and wetland wildlife habitats.

TECHNOLOGIES THAT STORE AND AUGMENT WATER SUPPLIES

Storage Facilities.—The Federal Government has a sizable investment (at least $26 billion) in completed water resource projects and owns some 2,000 dams, ranging in size from small reservoirs to large, multipurpose projects. While the benefits to irrigators and other users have been sizable, the costs have also been substantial. Barriers to new, large-scale developments are not technological; they are physical, economic, and environmental. **Because of these constraints, many experts expect that the Federal role in building and operating new, large-scale water-storage facilities will diminish markedly in the future.** New storage facilities are likely to be smaller, and their construction may depend increasingly on private and non-Federal public investment. Innovative cost-sharing arrangements could be encouraged between private and public developers and among local, State, and Federal governments.

Desalination.—Desalination (removal of dissolved salts from brackish water, seawater, or salt-degraded water) is a technology that can supplement freshwater supplies. Desalination can be accomplished by many methods and has proven to be reliable for small amounts of water. **High costs are the major current limitation to use of desalination; further development is needed before the process can produce large volumes of low-cost freshwater.**

Interbasin Transfers.—Current attention focuses on proposals to transfer water from areas of supposed surplus (e.g., Alaska and the Missouri River) to Western stream systems for irrigation use. Such **transfers will present considerable problems for the foreseeable future.** First, the cost of irrigation water from an interbasin transfer would probably be prohibitively expensive. Second, such transfers will present complicated environmental, political, legal, and institutional problems. **Most important, however, surplus water may not be available for transfer since many areas are realizing the present and future values of their water onsite.**

TECHNOLOGIES THAT CONSERVE EXISTING WATER SUPPLIES

Water Delivery Systems for Irrigation.—A variety of technologies show potential for improving water delivery flexibility. **While the agronomic benefits of new water-delivery technologies are likely to be substantial, existing irrigation facilities and practices may require extensive modifications before these benefits can be realized.**

Seepage Control.—Seepage occurs through the sides and bottoms of reservoirs and canals. Its extent depends largely on geology, soils, and topography.

Water "losses" caused by seepage can be large enough in some areas to prevent reservoirs from filling; however, estimates of the problem's magnitude are difficult to make and vary widely. **Although technologies to reduce seepage are available, control is costly, a primary limitation to use.** As the relationship between wildlife populations and standing water from inefficient irrigation is explored more fully, other limitations to use of such technologies may be identified.

Evaporation Control.—In arid/semiarid lands, evaporation is high. In some regions, reservoir evaporation may reach about 40 percent of usable storage. Since conserving collected water is one of the most economical methods of maintaining an adequate water supply, considerable research has been undertaken. **Results from use of evaporation-control technologies have been variable and often disappointing.** Reflective coatings and surface film are unstable and ineffective if the water surface is not still. Small reservoirs arranged in clusters and of varying depths experience substantially reduced evaporation when volumes are managed to minimize the exposed surface area. Mechanical covers show high potential for use on small reservoirs, stock tanks, and ponds.

Vegetation Management In and Near Surface Water.—Riparian zones constitute a small fraction of Western lands. They are significant to agriculture, however, and provide high-quality forage for livestock and are important in maintaining water quality. Many water experts believe that water "saved" by removing riparian vegetation remains in ground or surface waters for direct human use. However, **recent research indicates that plant removal from riparian zones does not necessarily make more water available for other immediate uses.**

Aquatic plants present a special problem for irrigators because they interfere with water movement, disrupt control devices, cause leaks in canal linings, and lose water to evaporation at rates greater than would occur from open-water surfaces. **Perhaps the most effective and least costly approach to aquatic-plant management is prevention.** But where aquatic weeds are present, mechanical, biological, and chemical methods of control are available. Of these, the chemical methods are faster and easier; however, they involve problems of water pollution.

Technologies Affecting Soil Water

Many opportunities for improving soil-water conditions exist, both where precipitation is used to supply crop- and forage-water needs (rangeland and dryland agriculture) and where additional water is supplied to fulfill crop-water requirements (irrigation). Technologies that conserve precipitation include practices that shape the soil surface, manage the soil cover, and change the physical or chemical properties of soil. Technologies that supplement soil-water supplies include drip irrigation, surface irrigation, sprinkler irrigation, and subsurface irrigation. **Effective use of precipitation and irrigation water often requires the use of more than one technology and skillful management of plants, water, and soil. The extent of soil-water increase that can be expected with the adoption of a particular technology or set of technologies is difficult to quantify, given the wide variability in site conditions across the arid and semiarid region.**

Some water-conserving practices have been adopted by producers, but numerous barriers remain to their widespread application. First, many of these technologies are effective only under certain soil and/or climatic conditions. Where

site conditions are not appropriate, application can yield little or no improvement in soil-water conditions. Second, some practices require large economic investments for equipment, fuel, and labor; application costs may outweigh their benefits in terms of higher farm or ranch profits. Third, the use of some technologies is hindered by Federal and State institutions. For example, mechanical land treatments on public rangelands by individuals are often prohibited; water saved by irrigators is often not allowed for their reuse. Finally, some practices are difficult to incorporate into existing farm and ranch operations and in some cases require new equipment or skills.

Soil salinization of irrigated lands and other effects of irrigation on natural resources (e.g., ground water depletion) lead many experts to believe that present irrigation agriculture is not sustainable and that existing practices will not make the contributions to agricultural growth that they have in the past. If a shift to limited irrigation or dryland or rangeland agriculture does occur, Western agriculture will face a period of economic and social readjustment which will be facilitated by development of a wide range of new opportunities for production.

Technologies Affecting Water-Use Efficiency of Plants and Animals

In arid and semiarid lands, the efficiency with which organisms use water has important implications for sustaining all types of agriculture, influencing the growth, distribution, and survival of plants and animals. Plants and animals have evolved a number of different ways of coping with water shortages; no single factor completely controls their responses. Tapping these traits may provide new opportunities for sustainable arid/semiarid agriculture.

IMPROVING PLANTS AND ANIMALS WITH BIOTECHNOLOGY

Biotechnologies include intensive new methods of introducing genetic variation into bacteria, plants, and animals and reproducing the results. **Specific applications of biotechnology to the problems of water use in arid and semiarid lands are underway and are likely to increase substantially in the next 10 to 15 years.**

Tissue culture of rangeland, dryland, and irrigated crops is in commercial use and analogous methods are used in animal breeding. Protoplast fusion and recombinant DNA technologies are promising, but they face a potentially long period of basic research before being widely applicable.

INNOVATIONS IN CLASSICAL PLANT AND ANIMAL BREEDING

Traditional methods of improving plants and animals will remain important. These techniques have accounted for yield increases of as much as 1 to 3 percent per acre per year for major annual crops. Range-plant breeding has been revitalized by the need for surface-mined land reclamation. Classical crop-plant breeding is likely to undergo an important shift in focus, however, as breeding for water stress becomes more important.

Some animal-breeding technology is available only to large ranches with high incomes. Other methods promise to make important new germplasm available to small ranchers for the first time. **Major economic changes are occurring in the livestock industry, some of which are linked to the decreasing avail-**

ability of inexpensive irrigated grains and forage. Shifts in the distribution of feedlots, the demand for red meat, and the relative importance of sheep and goats may have substantial implications for innovations in animal breeding.

CHOOSING ADAPTED PLANTS AND ANIMALS

The broader use of native organisms and the domestication of new crops have potential for alleviating some of the environmental problems caused by agriculture in the past and for tailoring it more specifically to arid and semiarid lands. Promising crop candidates include amaranth, tepary bean, guar, cowpea, jojoba, guayule, saltbush, mesquite, buffalo gourd, and milkweed. These are food and fiber crops, biomass energy plants, or sources of industrial products. Their status varies widely. At least one, grain amaranth, may be poised for major entry into the agricultural market. Most others face major institutional hurdles: lack of an established market and infrastructure, disinterest from the established agricultural community, and incomplete research. Western agriculture may include "new" animals in the future, but the use of rabbits, elk, buffalo, and other species will probably not increase rapidly in the short term.

Salt-tolerant organisms may extend the agricultural life of areas that are naturally saline or that result from agricultural mismanagement. **Adapting already salt-tolerant organisms for agriculture may be faster than adding salt tolerance to crops that now require freshwater.** Salt-tolerant crops of the future may include algae, bacteria, and blue-green algae as well as higher plants.*

Technologies Affecting Ground Water

Ground water use in the Western United States almost tripled between 1950 and 1975, and the ground water percentage of the total water withdrawn in the region nearly doubled. **Much of this increase in ground water use was made possible by technologies that permit the withdrawal of ever-deeper supplies at ever-faster rates, often in excess of recharge. This ground water "mining" has led to the noticeable depletion of ground water in many of the agricultural areas dependent on it.** Technologies to recharge these supplies artificially depend on a water surplus during at least some portion of each year to use for recharge. Their effectiveness is also very site-specific, dependent on suitable geologic characteristics and availability of land where recharge ponds are to be used. **In some situations, ground water overdraft may cause the collapse (commonly referred to as "subsidence") of underground, water-bearing formations. This process renders them incapable of fully reabsorbing or transmitting recharge waters and causes displacement of surface structures.** In many of the areas most affected by ground water overdraft, the **total** available renewable water resources are being completely consumed each year.

Water quality among the major ground-water resource regions varies considerably with ground-water recharge rates, rock chemistry, and human waste-disposal practices. Once a ground water aquifer becomes contaminated, there is relatively little that can be done technologically and in a manner that is economically feasible to remove or contain the contaminant. **Control of toxic and noxious substances in surface and subsurface waters will probably remain the only feasible ground water pollution-control technology in the foreseeable future.**

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*Higher plants are those such as conifers and flowering plants, which possess a well-developed conducting system. Plants such as mosses, fungi, and algae are not part of this group.

While irrigated agriculture has consumed the largest volume of ground water in recent decades in the Western United States, municipal and industrial uses have also become increasingly important. Many Western cities are now dependent on ground water and have a greater stake in its quantity and quality. **The social costs of declining water tables and increasing contamination of ground water resources of the Western United States must be addressed as both an agricultural and a broader social and public health problem. Until more understanding has been gained, the most appropriate ground water technology may be prudent and conservative management.**

Selected Technologies Affecting Land and Water Management

Modern management technologies are developing rapidly and have potential for sustaining agriculture in arid and semiarid lands. They represent a wide combination of individual practices involving animals, plants, cultivation equipment, irrigation systems, and computers. Few attributes are shared: some are capital-intensive; others substitute labor for capital. Some are highly specialized, while others are diversified. At least two features are common. **The most promising technologies are based on an understanding of the operation and limitations of the natural hydrologic cycle and they usually rely on significant amounts of information about the natural processes involved at the particular site.**

WATER-MANAGEMENT TECHNOLOGIES

Water management includes flexible cropping, irrigation scheduling, water reuse, conjunctive use of surface and ground water, and crop enclosures. Several of these rely on relatively sophisticated methods of assessing soil and plant water requirements. Additional research is needed to validate the accuracy of some techniques. **More well-developed water-management technologies may not be available to managers because of high costs, a lack of trained personnel or suitable programs to transfer information to the producer, or the manager's inability to implement recommendations.** Federal policies may, in some cases, impose an additional constraint on technology adoption.

Reuse of municipal wastewater may represent a source of additional irrigation water and a possible method to reduce water pollution. Before this technology is implemented, however, questions must be resolved regarding its long-term effects on renewable resources and health. Legal, economic, and policy questions about ownership of reused water, its market value, and its allocation to uses besides agriculture must be answered. Enclosures for plants and fish, especially those using solar energy, are presently suitable only for high-value agricultural products.

LAND-USE MANAGEMENT TECHNOLOGIES

With uncertain economic and resource conditions, such as increasing energy costs and unknown water availability, production specialization may involve increased risks. Therefore, **technologies that integrate different types of land use and different types of agricultural and nonagricultural products are especially promising for stabilizing economic risk.** They include alternative agriculture, multiple land use on rangelands and farmlands, and animal mixtures on rangelands. These more complex management methods have received little research attention. They have potential for improving use of arid-

and semiarid-land resources and for increasing farm income. In the past, interested private experimenters have often been isolated from one another, and this has hindered wide dissemination of knowledge about these practices.

Alternative types of agriculture have largely unexplored potentials in arid and semiarid regions. These new systems may include complex mixtures of crops in one field, perennial grains or tree crops instead of annuals, or the elimination of synthetic pesticides and fertilizers. Generally, they rely heavily on natural biological processes.

Diversified farming and ranching have important benefits in areas where climate is unpredictable or the economy is unstable. Most types of land are amenable to some type of diversified enterprise; however, markets for products, compatibility of multiple purposes with agriculture, restrictions on the use of public land, and specialization of agricultural production hinder adoption of these management systems.

COMPUTERS AND INFORMATION MANAGEMENT

Computers are having a major impact on agricultural extension services and on individual farmers and ranchers. They assist in recordkeeping and help prevent costly management errors. **Their role is likely to increase in the future, but questions remain regarding fair access to computerized information and the reluctance of many Western farmers and ranchers to adopt computer technology.**

POLICY ISSUES AND OPTIONS FOR CONGRESS

In recent years, awareness has increased that most of the West's water-resource problems transcend State boundaries and are extremely difficult in nature, involving a complex web of physical, chemical, biological, economic, legal, and sociopolitical issues that affect adoption of water-related technology. Successful application of technology is site-specific and depends on an understanding of the interrelated impacts on the agricultural resource base. The presence of technology is not sufficient to address the problems of Western agriculture and water use. Technologies must be combined with improved data for planning and improved Federal policies and programs that recognize the interrelated nature of renewable resources, including water, on which agriculture depends. Moreover, achieving long-term agricultural productivity in the West must involve taking into account long-term social and ecological factors, as well as economic ones.

The following policy issues and options have been identified by OTA as those most critical for congressional action over the next few years. They are grouped in three major categories (treating renewable resources as systems, sustaining long-term productivity, and involving users in decisionmaking) to parallel the three fundamental findings of this assessment. They are not listed in any order of priority.

Treating Renewable Resources as Systems

This major action area is divided into three categories:

1. how Western scientists, water users, universities, and the public-at-large can play an expanded role in decisionmaking about water and Western agriculture;

2. how congressional decisionmaking can be strengthened; and
3. how other Federal and State Government agencies can improve specific programs.

Issue 1: The Need for an Interdisciplinary Program of Basic and Applied Research on Arid/Semiarid-Water Resources

The Nation's universities, water users, and private sector have a variety of research programs on water resources and water-resource management and could provide unique services in arid/semiarid-water resources research and decisionmaking. At present, however, links are often not made to broader national or regional problems and there is a lack of a national coherence and synthesis of university water-related research. Progress in Western water-resources research, both basic and applied, could benefit substantially by the creation of a broad coordinating mechanism to focus and interrelate the multidisciplinary talents of the academic community and water users with the resources of the private sector. The Nation's universities are especially important to tap at a time when Federal assistance to coordinate water planning and research has effectively disappeared.

Option: Congress could establish a National Center for Water Resources Research to provide a coherent and coordinated mechanism for the Nation's university research programs in water resources and water-resource management for problem-solving and policymaking.

The mission of this center could include:

1. Undertaking an interdisciplinary program of basic and applied research on water resources and water-resource management, including strong programs in the natural sciences, engineering, and social sciences, such as resource economics and law as they pertain to water-resources programs. The center could further assist in the conduct of site-specific research being carried out under State auspices.
2. Developing and providing advanced and sophisticated research facilities on a scale required to cope with the broad nature of water-resources problems, and often not affordable by single universities, to be used by resident staff, innovative producers, and university scientists.
3. Undertaking a program to develop and test conventional and emerging technologies for application to water-resources problems in United States arid/semiarid lands, including problems of agriculture and its sustainability in arid/semiarid lands, and coordinating such efforts with existing government research by USDA and State agricultural experiment stations.
4. Serving as an objective, nonpartisan, and continuing national source of information for Congress when formulating public policy dealing with water resources, and as a link to public agencies, water users, and the private sector for application of research findings.

This center could serve as a base for marshaling university and private industry talents and for augmenting, but not in any sense competing with, university work already underway. Using the successful experience of the National Center for Atmospheric Research (NCAR), an institution created some 20 years ago by an act of Congress, the center could be managed and operated by a consortium of universities with doctoral-level programs in water resources. An essential aspect for effective operation is that prime responsibility for program initiatives reside with this consortium since the university community is closest to the research and its potentials.

Issue 2: The Need for Congress to Have Reliable Ongoing Information About the State of the Nation's Renewable Natural Resources

The assessment finds that existing data available for congressional decisionmaking is scattered throughout the Federal Government in a variety of forms. These data were not collected with the intention that each piece would be part of an integrated and self-consistent base for Congress to use in making decisions affecting resource sustainability. Moreover, existing data on components of the resource base on which agriculture depends are seldom synthesized because the data may be in noncompatible forms and no single agency has had the ongoing responsibility to seek compatibility or synthesis.

Congress needs improved information for setting near- and long-term goals for sustainable use of Western water and agricultural lands. This information should focus on congressional needs and emphasize systems analysis of the natural resources on which agriculture depends. Ongoing analysis and synthesis of existing data bases—e.g., through an office of resource analysis—could provide improved information on the dynamics of the resource system and how interactions (natural and manipulated) among resource components affect the sustainability of Western agriculture.

Option 1: Congress could develop a bipartisan unit within the legislative branch with the principle purpose to provide Congress with ongoing quantitative evaluations of the state of the renewable natural resource system as a consequence of near- and long-term congressional policies. The unit's program should be interdisciplinary and multidisciplinary, with access to state-of-the-art computer facilities to conduct comprehensive data analysis and synthesis from existing data sources on specific topics requested by Congress. Such a unit could identify data gaps important to U.S. decisionmaking that affects the sustainability of the renewable resource base. It would require independence and flexibility to obtain and interpret data in a nonbiased fashion for the entire Congress. Specific organizational structure and legislative authority would have to be developed to meet the unit's defined purposes.

The first step in considering this option might be a workshop of interested and involved congressional, executive, State, and local participants to examine existing problems, the history of similar attempts and experiments in data synthesis, and possibilities for action. This workshop might be combined with the formation of a joint committee of members from relevant House and Senate committees to plan subsequent steps.

Option 2: As an alternative to option 1, Congress could develop an executive branch unit to provide ongoing quantitative evaluations for congressional decisionmaking affecting resource sustainability. On congressional request, this unit could coordinate, integrate, and interpret existing information similar to that noted for the legislative unit proposed in option 1, and report directly to Congress. Traditionally, Congress has turned to the executive branch for answers to fundamental questions involved with its policymaking. Existing executive agencies have personnel, equipment, and many separate data bases; some career staff have experience in aspects of water- or agricultural-data collection and analyses. Partial funding might be available for this option through redirection of existing funds from lower priority executive activities, as determined by Congress.

Possible disadvantages of this option relate to the adequacy of existing agencies to incorporate this function and the nature of executive branch programs in general. The capacity of existing executive agencies for long-term and multidisciplinary resource systems planning is seriously lacking. The placement of

this systems capacity in the executive branch poses concerns about continuity. Programs and priorities in the executive branch change with administrations. A small new executive unit is unlikely to be in a secure position to provide objectivity, coherence, and continuity, essential requirements for effective long-term data syntheses. In recent years Congress has found it necessary to develop inhouse expertise to supplement executive branch input in areas requiring focused analysis, integration of issues or activities, and verification or clarification of executive branch reports.

Issue 3: The Need to Integrate Water-Related Agricultural Activities in Government Agencies

Federal agencies charged with implementing congressional policies and programs need a perspective that interrelates technological impacts as they affect various components and ultimately the agricultural system and long-term productivity of the region. The following options are specific areas conducive to immediate congressional action. All four are compatible.

Option 1: Congress, through the hearing process, could initiate discussions with USDA for the purpose of designing and establishing a high-level office to integrate and provide coherence to water-related and agricultural activities within the Department. This office of resource coordination should be placed at an appropriately high level—e.g., in the Office of the Secretary of Agriculture—to minimize confusion in organizational responsibilities and to ensure coordination and integration of activities among all specialized agencies of the Department. This office could have responsibilities for analyzing programs of the specialized agencies, for helping formulate a systems perspective that integrates the agencies' resource programs, for minimizing narrowness of focus and potentially conflicting activities, and for overseeing implementation of integrated programs in research, technology development, and production in long-range sustainable arid/semiarid agriculture. An office at the level of the Secretary could emphasize the importance of agriculture's natural resource base and make visible the role of the Department in protecting it. It could encourage the Department to take advantage of the most modern systems-analysis technology, technology that has not commonly been used in agriculture.

Option 2: Congress could instruct Federal land-management agencies responsible for Western areas to increase efforts in water resources and water-resources management pursuant to their existing multiple-use responsibilities for managing natural resources on public lands. Existing multiple-use statutory guidelines prohibit optimization of single measurable uses (e.g., timber and cows) at the expense of less quantifiable uses (e.g., watershed and recreation), and they forbid practices that impair long-term land productivity. This option will entail a reorganization of agency priorities such that more emphasis is placed on long-term benefits from water management and less emphasis is placed on short-term revenue-producing benefits from grazing and timber production. This is an area of considerable importance for long-term Western water-resources management and arid/semiarid agriculture because most Western surface water-producing areas are on public lands.

Option 3: Congress could assist States to develop and integrate computerized data bases for the wide range of hydrologic data now scattered among State and local agencies and private industry. Such information is not being entered into Federal data storage systems but is increasingly needed for effective water-resources planning and management at the regional, State, and local levels. Data bases could be designed to ensure integration of water quality and quantity data for systems planning. Federal funds to States for water-resources

planning and coordination could be allocated for State participation in this data system. The private sector could share data and give advice on the best available technology for data storage, retrieval, and processing.

Option 4: Congress could expand mandates of Federal agencies responsible for water-project development and maintenance to take into account needs of instream flow, a subject that has had inadequate and, in recent years, reduced attention at the Federal level. Some minimum instream flow requirements are essential for rivers for dilution, hydroelectric generation, and fish and wildlife habitat protection. In many river systems of the West, however, virtually the entire flow of the river is committed already to various offstream uses. In view of the geographic nature of river systems, an increased Federal role is needed to help define and monitor instream flow requirements of Western of Western rivers. The maintenance of instream flows may make it possible to maintain acceptable water-quality levels in some Western rivers without the need for greatly increased water-treatment facilities. An improved understanding of instream needs for the multiple purposes of Western river systems will also improve management information for planning long-term requirements of the various water users.

Sustaining Long-Term Productivity

Issue 1: The Need for a Strong Federal Role in Water Quality for Sustainable Western Agriculture

Because of the West's low or sporadic water-volume flows, the region cannot absorb the levels of industrial, municipal, and agricultural pollution possible for more water-abundant regions. Without the maintenance of a strong and committed Federal role, it is conceivable that agriculture in some areas may go out of production because of water-quality degradation rather than loss of supplies.

Three options are particularly important, and all are compatible for immediate congressional action.

Option 1: Congress could maintain a firm commitment under the Clean Water Act to strong water-quality standards that are applicable across the Nation in order to ensure that economic burdens and benefits are evenly shared among States and to avoid industrial "shopping" for areas where water-quality standards might be low. National water-quality standards must be stringent in order to protect the range of present and future interests in water, some of which require the highest standards (e.g., for drinking-water purposes). Existing requirements could be retained, and any new or revised water-quality standards could be made to enhance the quality rather than allow degradation.

Option 2: Congress could refine national nonpoint source policy under the Clean Water Act and particularly under section 208 of that act, and accelerate implementation of controls on water pollution from nonpoint agricultural sources. Knowledge exists to reduce water pollution from agricultural nonpoint (diffused) sources through the adoption of improved management practices. As part of this action, Congress could strengthen Federal support to State and local efforts to achieve nonpoint source pollution reduction. Increased Federal support could come in a number of forms, including providing incentives, assisting economically depressed farmers to adopt better practices, and offering technical and financial assistance for training farmers and ranchers to implement control measures.

Option 3: Congress could increase research and monitoring of short- and long-term agricultural and public health effects of Western surface and ground water-quality deterioration. Little water-quality research has been undertaken on a comprehensive areawide basis or on related health and environmental impacts of water-quality degradation. Existing standards may not adequately protect the public in some areas, while others may be too stringent. Particular focus could be given to synthesis of existing information, most of which is scattered and contaminant-specific, and to research on likely agricultural contaminants that are detrimental to other uses and on contaminants from other uses that are detrimental to agriculture. Such activities could provide valuable information for national and local policymaking to protect ground waters and surface waters from contamination.

Issue 2: Protecting and Maintaining the Long-Term Productivity of Rain-Fed Agricultural Resources

Protecting the renewable resource base for productive rain-fed agriculture in the arid/ semiarid West is a growing national concern, especially since irrigated production in some areas is likely to decrease because of water problems. The following two options are important and compatible.

Option 1: Congress could withdraw those Federal programs that induce conversion of rangeland to uses not suited to that land and thus cause resource degradation that ultimately limits long-term productivity. One method of achieving this could be to require that applicants for Federal agricultural assistance certify that their land is not new cropland or, if so, to demonstrate that a conservation system approved by the local conservation district is, or will be, in place for the land to be put into production. The land-capability classes could be used as a guide for determining what lands are unsuited for cultivation and thus ineligible for Federal assistance, except with an approved conservation plan.

Option 2: Congress could direct that USDA increase its R&D focus on rain-fed agricultural systems—both dryland and rangeland. Significant opportunities exist to develop and expand dryland and rangeland public research into broader areas of focus than now exist. Increased support is needed if this Nation is to have the range of alternatives necessary to ensure flexibility in meeting anticipated and unanticipated future needs for agricultural production in the West. As one means of implementing this option, Congress could hold hearings with USDA to examine that Department's existing field research stations. The purpose would be to identify and convert appropriate stations to facilities for testing and developing technologies, based on an integrated resource approach, to sustain or improve rain-fed agricultural productivity of these arid/semiarid lands over the long term. The work could be made readily available to producers through special pilot projects and field-days and through the conventional extension programs.

Involving Users in Decisionmaking

Issue 1: Achieving Equity in Western Water Availability and Distribution

Lasting settlement of conflicts over Western water use must involve principles of equity and fairness for current users, for those whose rights have yet to be developed, for those whose communities and lifestyles might be affected by major water shifts, and for new users with economic power who seek to

buy water supplies. Already, perceptions are growing among poorer farmers and American Indians that existing Western institutions responsible for water distribution and development have not treated them fairly. Two kinds of congressional actions are important and compatible here.

Option 1: Congress, in its leadership role with reserved water rights, could increase its efforts to address the complex long-term task of resolving issues surrounding Indian reserved water rights under the Federal reserved rights doctrine by taking two initial actions: 1) increase opportunity for ongoing representation of Indian interests in both Houses of Congress, and 2) provide a mechanism through legislation to protect reserved rights and equity interests where the rights are already fully appropriated; that is, by compensating the reserved rightholder and by eventually reallocating the water to that rightholder. Resolving reserved water-rights issues is an essential step in the effective long-term planning and development of sustainable Western agriculture. Congress might consider a variety of approaches to increase its activity in negotiation and representation of Indian water interests including the appointment of a joint House and Senate committee, a special committee or task force to define more clearly appropriate future action, or creation of an ongoing subcommittee on Indian affairs.

Option 2: Congress could help to ensure that equity and fairness are elements of any water-resources distribution and reallocation decision for disadvantaged people, especially poorer farmers, by establishing a Select Committee on Disadvantaged People and Renewable Resources to investigate and recommend legislation to protect these interests. Among the topics the committee could address are mechanisms for: 1) educating Western disadvantaged people about their stake in water management, and 2) bargaining collectively for Western water rights that may be bought or sold in a market framework. Such mechanisms could be important in helping disadvantaged people increase participation in water-use and reallocation decisions in the arid/semiarid region.

Issue 2: Understanding the Impacts of Water Prices on Adoption of Technology

Federal reform of water-project repayment plans and policies is underway. Reduced Federal subsidies will make Western water more expensive for all users. Impacts on agriculture, a major water user, could be significant. The outcome for agriculture is not well understood or studied. To help ensure that reforms produce desirable results, a careful study and documentation of existing markets and anticipated agricultural consequences is needed.

Option: Congress could seek the assistance of the Congressional Budget Office (CBO) to study the short- and long-term economic consequences of reduced Federal water subsidies and increased water-market activity on agricultural users and others affected by agriculture. A CBO analysis could help Congress: 1) understand the possible near- and long-term economic consequences of reforming water-project repayment plans and programs for Western agriculture and nonfarm economies; and 2) provide guidance, monitoring, and assistance with the transition to greater use of water markets to the extent that is likely to result from reduced development subsidies. While scattered studies are beginning to appear on the economics of water in the West, CBO could provide an objective, comprehensive synthesis of available socioeconomic information and a focused analysis of the Federal connection with the economics of Western water and agricultural practices.

Issue 3: Improving the Effectiveness of Water-Related Technologies for Sustainable Agriculture

Development and successful application of water-related technologies depend, in part, on the ability of the researcher and user to adapt them to local conditions. Research for both onsite and offsite technologies commonly suffers from questions of relevance and practicality for a particular agricultural site and user.

Option: Congress could direct the establishment of two user oversight groups specifically focused on Western water and agriculture. One user group could address onsite water-conserving technology potentials and needs and provide advice principally to USDA. The other user group could focus on offsite water augmentation technologies for downstream agriculture. This second group could advise Federal agencies responsible for those water-related technologies (e.g., weather modification, watershed management, snowmelt forecasting) applied upstream or in highland areas offsite from arid/semiarid agriculture but having potential water-related impacts for downstream or lowland agriculture. Each user group could advise appropriate congressional committees as well.

By making use of innovative producers and by bringing the research to the farm or ranch, this option could improve research/user interaction, an essential aspect of effective technology development and adoption now seriously lacking in many areas. User groups could assist Congress to determine whether existing programs are doing the job needed for sustainable agriculture from the Western users' perspective.

Concerns about this option relate to the possible effectiveness of the user groups. At present, a National Agricultural Research and Extension Users Advisory Board (UAB) exists pursuant to legislation in the Food and Agriculture Act of 1977. A recent OTA report* on the food and agricultural research system found this board's effect on USDA research priorities to be unclear. Other concerns are that researchers who interact with user groups would be taking time that might be spent otherwise with laboratory or field work. Moreover, the focus of particular users might be on short-term economic solutions rather than long-range issues involved with the development of technologies for sustainable agriculture.

Precautions in establishing these groups will be required to ensure that they effectively represent the range of users' views, include long-range interests, and have the capacity to evaluate and scrutinize Federal agency research work. Congress could require that users be nominated by representative agricultural organizations and have access, when necessary, to scientific expertise independent of the Federal agencies. Membership rotation could ensure a flow of new ideas to minimize loss of research time on new potentials.

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*An Assessment of the United States Food and Agricultural Research System, OTA-F-155, December 1981.

NOTE: Copies of the full report, "Water-Related Technologies for Sustainable Agriculture in U.S. Arid and Semiarid Lands," can be purchased from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402, GPO stock No. 052-003-00930-7.

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